Field Evaluation of Commercial Off-the-Shelf Spatial Repellents Against the Asian Tiger Mosquito, *Aedes albopictus* (Skuse), and the Potential for Use During Deployment

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ABSTRACT

The Testing and Evaluation Department of the US Navy Entomology Center of Excellence (NECE), Naval Air Station, Jacksonville, Florida, is dedicated to the evaluation of novel equipment and vector control techniques to provide guidance on effective protection measures against human pathogens transmitted by blood-feeding arthropods. Personal protective measures (PPM), to include repellents, are part of a series of techniques that contribute toward reducing human-vector contact for globally and domestically deployed military forces. However, improper PPM use and limited availability has created vulnerabilities, causing troops to purchase spatial repellent products that are not approved by the Department of Defense. In order to ensure the most effective products are available, NECE has evaluated the spatial repellency response of *Aedes albopictus* (Skuse) to 4 commercial off-the-shelf (COTS) spatial repellents to provide technical guidance on proper use and effectiveness. The COTS products evaluated ThermaCELL, OFF! Clip On, Lentek Bite Shield, and Bug Button Mosquito Eliminator. A Biogents Sentinel (BGS) trap was placed in 5 locations with a spatial repellent device suspended at the level of the BGS trap opening over 4 of them (the fifth was control). Each trap catch was collected every 12 hours, at which time the spatial repellent device was rotated to the next position. Using this method, each spatial repellent device and control was rotated across each of the 5 locations a total of 6 times. Spatial repellent efficiency was evaluated by comparing the total number of mosquitoes collected in the BGS traps during a 12-hour period. The number of adult mosquitoes repelled by the ThermaCell spatial repellent was significantly more than other spatial repellents with the exception of OFF!. These data indicate that COTS products using repellent insecticide rather than botanicals are more effective at deterring *Ae. albopictus* from biting a host.

Humans have used repellents to protect themselves from pestiferous blood-feeding insects since prehistoric times. The most probable primitive repellent is the use of smoke to mask kairomones (odors from humans who are attractive to host-seeking mosquitoes) and provide relief from insect biting pressure. A personal protective measures (PPM) system that includes the use of repellents is vital to efforts in reducing transmission of vector-borne diseases (VBDs) to military personnel. Prior to World War I when synthetic repellents were introduced, natural plant oils were the principal means of protection against pestiferous insects.[1] Today, the most commonly used repellents are topically applied products, or topical repellents. Topical repellents constitute a wide array of chemicals ranging from natural botanicals such as citronella to synthetically derived N,N-Diethyl-3-methyl benzamide (deet). However, the use of topical repellents is often complicated by an unpleasant smell, oily residue, and dermal irritation. Furthermore, studies to improve the longevity of topically applied repellents have shown a loss in efficiency due to transdermal absorption.[2] To improve user acceptance, additional repellent application methods should be evaluated for efficacy.

The spatial action of repellents is not a novel concept,[3] but their use among the military has been sporadic at best. Although field evaluations of ThermaCELL (The Schawbel Corp, Bedford, MA) have shown the capability to repel biting insects up to 90% for 6 hours,[4] no spatial repellents have been issued a National Stock Number or approved for use by the Department of Defense (DoD).[5] Currently recommended PPM for military members is effective when used properly but has largely been unsuccessful in theater due to limited availability, improper use, and troop concerns with dermal exposure.

The Navy Entomology Center of Excellence (NECE), Naval Air Station, Jacksonville, Florida, evaluates and

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tests novel techniques or equipment used for preventing VBDs. Commercial off-the-shelf (COTS) spatial repellents are being purchased and used by troops, raising product awareness and popularity. The increase in product use among troops has initiated spatial repellent testing at NECE to provide technical guidance for proper use and product effectiveness. In this article, results from the spatial repellent evaluations and their potential role for use by the military are discussed.

MILITARY PERSONAL PROTECTIVE MEASURES

As Peterson states, "War and disease truly are deadly comrades."[6] It is common knowledge that insect-vectored diseases have devastated military campaigns throughout history. The Napoleonic campaigns alone were crippled by plague, typhus, and yellow fever, literally rewriting military history. Military campaigns create a situation of immunologically naive populations in a concentrated area, exposure to foreign pathogens, and societal stress promoting the perfect storm for a disease epidemic among troops. Due to post-World War II advancements in medical entomology and military medicine, insect-vectored pathogens have had a smaller impact on war. However, deployed troops still face VBD threats that have been both deadly and debilitating to the mission. In 2003, 80 of 225 Marines deployed to Liberia for 10 days fell ill to malaria.[7] Korzeniewski and Olszanski[8] reported a 1% leishmaniasis infection rate among US service members during operation Iraqi Freedom. In 2009, the US Navy deployed multiple teams to Key West, Florida, to provide operational assistance against dengue outbreaks. The continued occurrence of illness caused by VBDs threatens operational readiness of the military and exposes a gap in protection for US troops. However, this gap in protection is not from a lack of instruction or understanding of how to protect troops against vectors and diseases, but rather an apparent reluctance, or outright refusal, of some individual personnel to fully comply with the PPM guidelines.

Currently, the DoD promotes an insect repellent system that outlines 3 protection strategies: (*a*) deet application to exposed skin, (*b*) treatment of uniforms with permethrin, and (*c*) proper wear of uniforms to maximize coverage. This insect repellent system is required by the DoD when exposure to VBDs is likely. In addition, the DoD requires use of additional PPM such as permethrin treated bed nets.[5] This system will provide maximum protection only when components are used properly.

User acceptability of PPM is a constant challenge to its effectiveness. Sanders et al[9] reported that responders in a 2004 study of personnel returning from Iraq and Afghanistan indicated that a majority (51.2%) never used deet, even though most (68.5%) knew that deet was readily available. Of those that did use deet, only 14.6% reported using it more than occasionally. Many fail to follow the DoD PPM guidelines for several reasons:

Manufacturer provided specifications and information for some current commercially available spatial repellent products.

Product	Type	Cost per Unit	Area Covered	Batteries	Butane	Length of Use	Mosquito	Biting Flies	Tick	Comments
ThermaCELL*	Allethrin	$29.99	225 sq ft	No	Yes	4 hours	Yes	Yes	No	Length of use is per insecticide pad. Butane cartridge lasts 12 hours.
ThermaCELL Lamp	Allethrin	$31.99	225 sq ft	No	Yes	4 hours	Yes	Yes	No	Length of use is per insecticide pad. Butane cartridge lasts 12 hours.
OFF! Clip On*	Metafluthrin	$10.00	Personal space	Yes	No	12 hours	Yes	No	No	Odorless
OFF! Lamp	Allethrin	$15.00	225 sq ft	No	No	4 hours	Yes	No	No	Candle used as heat source.
Bite Shield Clip On*	30% Geraniol	$29.99	15 ft radius, 2000 sq ft indoors	Yes	No	120 hours	Yes	Yes	Yes	Also repels lice, fleas, and fire ants.
Bite Shield wrist bands	20% Geraniol	$5.99	Personal space	No	No	120 hours	Yes	Yes	Yes	Also repels lice, fleas, and fire ants.
Bug Button*	Natural oils†	$1.00	Personal space	No	No	220 hours	Yes	Yes	Yes	Also repels lice and many stinging insects.
Flowtron FD-15	Citronella oil fragrance	$24.95	See comment	Yes	No	30 days	Yes	Yes	No	Manufacturer does not specify area covered

*Product evaluated in this study.
†Citronella oil, Phillipine geranium oil, Indonesian lemongrass oil

underestimating the risk of vectors and the diseases they transmit; improper use of insecticide treated bed nets and uniforms; and lack of trust in military issued deet. The lack of knowledge among personnel regarding regional vector threats and proper use of PPM can be addressed with additional training from their commands. However, command emphasis on proper use of insecticide treated bed nets, permethrin treated uniforms, and personal repellents is sometimes ineffective.[10] In addition, even when command emphasis is excellent, personnel are concerned with the short and long-term exposure of some PPM components. Kitchen[11] reported that personnel expressed concerns for their safety when using deet largely because of dermal sensitivities, unpleasant odors, and plasticizing effects. The required daily PPM use is an additional hurdle that further complicates the situation.[12]

Figure 1. Marketing imagery of COTS spatial repellent devices tested in this study:
A - ThermaCELL Mosquito Repellent (http://www.hermacell.com)
B - OFF! Clip On (http://www.off.com)
C - Lentek Blte Shield (http://www.koolatron.com)
D - Bug Button Mosquito Eliminator (http://www.bugbutton.com)

Additional tools should be added to the vector control toolbox to improve PPM strategies. Ideally, there should be a vector control component that is easily deployed, tactical, and requires minimal user participation. Product development, however, can take years of research and millions of dollars before something reaches the end user. Therefore, products that are currently available to the general public should be tested and evaluated for military use. Due to the popularity among outdoorsmen in the civilian market, commercially available spatial repellents have drawn the attention of DoD personnel for use against biting arthropods. The NECE initiated spatial repellent device testing and evaluation studies in Jacksonville, Florida, after careful evaluation of commercially available products and trends of use by DoD personnel.

SPATIAL REPELLENT DEVICE TESTING AND EVALUATION

Nolen et al[13] defined a spatial repellent as a compound, dispensed into the atmosphere of a 3 dimensional space, which inhibits the ability of host-seeking insects to locate a target. A repellent that is dispersed to protect a defined space can be distributed in several ways, including plastic or paper strips,[15-17] coils,[18] candles,[19] fan emanators,[20,21] and heat generating devices.[4,22] In addition, commercially available spatial products currently on the market using repellent insecticides* or natural oils have shown effectiveness. Overall, reports have shown that repellent insecticides provide the most protection, but natural oils have also shown spatial repellency that warrants proper testing and evaluation.[14,23,24] The Table presents a sample of the many spatial repellent products available to the end user, underscoring the difficulty involved in choosing an effective spatial repellent device for protection. Military end users are personnel who deploy both domestically and globally. It is our mission to provide guidance on safe and effective VBD prevention.

To find the best available spatial repellent devices and determine if any are suitable for military use, NECE evaluated 4 spatial repellent devices currently available on the market. The objective of this study was to determine the efficacy of COTS spatial repellents against *Aedes albopictus* (Skuse) (Asian Tiger Mosquito) and evaluate their durability for potential military use. Originally from Southeast Asia, the *Ae. albopictus* (Skuse) is established in 20 countries and has been reported in more than 50 worldwide.[25,26] This container-breeding species is a daytime biter and competent vector of many pathogens including dengue and chikungunya viruses.

The COTS devices evaluated (Figure 1) were: ThermaCELL; OFF! Clip On (S.C. Johnson & Son, Inc, Racine WI); Lentek Bite Shield (Koolatron, Brantford, Ontario, Canada); and Bug Button Mosquito Eliminator (Evergreen Research, Inc, Golden, CO). Biogents Sentinel traps (BGS traps) (Biogents AG, Regensburg, Germany) (Figure 2) were used to provide maximum artificial host attraction to container-breeding mosquitoes that are considered as primary vectors of dengue and chikungunya viruses.[27-30]

In a suburban neighborhood in Clay County, Florida, a single BGS trap was placed in each of 5 separate locations 20 m apart with a spatial repellent device suspended

*An insecticide with aromatic properties that repel insects from reaching their intended target. The insecticide repellents used in this study incorporate an inert absorbent pad impregnated with an insecticide with evaporative emissions repulsive to *Ae. albopictus*, discouraging them from approaching the protected individual.

Figure 2. One of the Biogents Sentinel traps placed at each of the 5 positions during the spatial repellent device study. The trap acted as an artificial host for the *Ae. albopictus* mosquito, using attractant and a 12 volt battery powered system to mimic convection currents created by a human body (green arrows). The mosquitoes enter the trap through the center opening (red arrow) and are trapped for collection.

from a shepherd's hook holder 0.30 m above the trap opening of each of 4 of them (Figure 3). The fifth BGS trap was control, without a suspended repellent device. The BGS traps were started between 6:30 AM and 7:00 AM with continual operation until 7:00 PM to 7:30 PM to obtain a 12 hour diel collection period. Each trap catch was collected every 12 hours, at which time the spatial repellent device was rotated to the next position. Using this method, each spatial repellent device (and control) was rotated across each of the 5 locations a total of 6 times. To ensure consistent operation among the devices, repellents were changed according to manufacture recommendations and power sources (butane, batteries) were changed daily. An analysis of variance was performed on the female mosquitoes collected in the BGS traps during this study with the null hypothesis of no significant difference between any of the treatments. The means were compared using a *t* test at 95% confidence interval. Operational notes were recorded throughout the study to document reliability of the devices during field use.

There were 867 female *Ae. albopictus* collected during this study. As shown in Figure 4, The number of adult mosquitoes repelled by the ThermaCELL spatial repellent was significantly greater than other spatial repellents with the exception of OFF! Clip On ($P>.001$). When compared to the control trap, ThermaCELL reduced trap capture by 76% and the OFF! Clip On reduced trap capture by 64%. The spatial repellent device using natural oils, Bug Button, did not significantly reduce trap capture when compared to the control trap. However, statistically the Lenteck Bite Shield performed as well as the OFF! Clip On and reduced trap capture by 43%. These data indicate that COTS devices using repellent insecticide rather than botanicals are more effective at deterring *Ae. albopictus* from biting a host.

SPATIAL REPELLENT DEVICE RELIABILITY

The ThermaCELL spatial repellent device operated without failure throughout this study. There are no batteries needed to power the device, but due to an internal heat generator, the device gets hot. In addition, this device requires timely user monitoring to change the insecticide pad every 4 hours and the butane cartridge every 12 hours for continuous operation. Furthermore, the manufacturer recommends that the device remain horizontal (not attached to the user) making it difficult for mobility. Use of this device by military members could cause logistical issues with resupply of insecticide pads and butane. A potential heat signature from the device is also a tactical concern.

The OFF! Clip On was less sturdy. During this study, one device failed due to the fan contacting the housing of the unit. This device can be carried directly on the user, facilitating mobility. It uses batteries as the power source and the insecticide pad lasts 12 hours, reducing the amount of attention needed when operating. The housing is a bright blue color, reducing the ability to blend in with the uniform, and the fan is audible during operation. Use of this device by military members could cause logistical issues with resupply of insecticide pads and batteries. The sounds produced by the fan and the color of the housing are also a potential tactical concern.

The Lentek Bite Shield device is sturdy but it was the least reliable of all the devices tested. Two devices failed requiring replacement during this study. This device uses batteries as the power source, its repellent cartridge lasts 120 hours, and it can be carried directly on the user, facilitating mobility. However, the batteries seem to drain quickly, causing the fan to slow and reducing the amount of repellent being dispersed. The housing is white, reducing the ability to blend in with the uniform, and the fan is audible during operation. Use of this device by military members could cause logistical challenges with resupply of batteries, and the sounds

Figure 3. Photos of each of the 4 test items suspended over the BGS Sentinel trap using rope and shepherd hooks:
A - ThermaCELL Mosquito Repellent
B - OFF! Clip On
C - Lentek Bite Shield
D - Bug Button Mosquito Eliminator

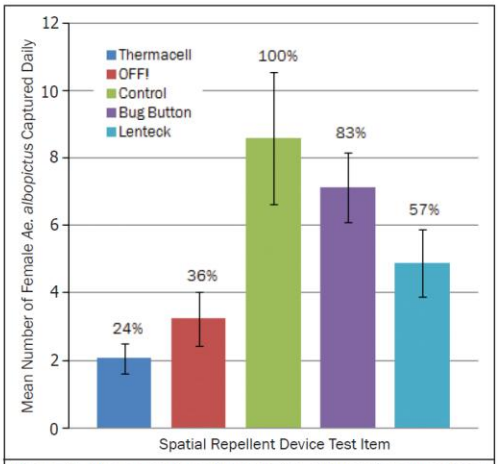

Figure 4. Mean number of female *Ae. albopictus* mosquities captured daily by traps protected by each spatial repellent device over entire study period. The control trap capture is considered to be the 100% baseline. The percentages shown for each device are calculated against the control trap capture total.

produced by the fan along with the color of the housing are potentially a tactical concern.

The Bug Button Mosquito Eliminator is a sturdy, solid disk providing easy set up and maintenance for the user. The manufacturer claims 220 hours of protection and the device can be carried directly on the user, maximizing mobility. There are no logistical concerns with this device making it easily deployable in theater. However, the bright yellow color of the disk does not allow the device to blend in with military uniforms.

SUMMARY

The DoD insect repellent system outlines all necessary measures to provide maximum personal protection against vector-borne diseases. However, lack of consistent participation by military personnel highlight a disconnect between PPM availability and what personnel will use. Even though deet was developed shortly after World War II, it continues to be the "gold standard" of topical repellents. Other personal repellents listed in government supply systems and those available to civilians present some of the same drawbacks mentioned earlier (dermal irritation, unpleasant odors, oily residue) that cause DoD personnel to avoid using deet. There is a need for an additional PPM that is simple to use and does not require dermal application. In theory, spatial repellents should be able to meet these requirements, but the logistical and reliability issues of currently available devices complicate their utility in a deployed environment, and would likely result in reduced use by personnel.

In NECE's spatial repellent study described in this article, it was determined that spatial repellent devices using repellent insecticides are the most efficient at protecting against *Ae. albopictus*, an important vector of dengue and chikungunya viruses.[31] Overall, the ThermaCELL spatial repellent device was the most effective device and is suitable for field use. Results from this study show that this device could potentially reduce biting pressure by 76%, providing a level of protection that will reduce VBD risk among personnel. This device works well for stationary situations where supplies are easily obtained and tactical issues are not a priority. However, this device is not ideal for use during deployments, highlighting a need for the development of a military grade spatial repellent device. Logistical and tactical concerns outlined in this article should be addressed. Future studies should be conducted to develop a military-specific spatial repellent device. The ideal device should be versatile (indoor/outdoor), portable, tactical, easily deployable, and contain repellent insecticides that vaporize at ambient temperatures.

The Navy Entomology Center of Excellence continues to test and evaluate spatial repellents and has partnered with the Walter Reed Army Institute of Research to

expand the idea of using spatial repellents to protect deployed forces. Additional PPMs should be made available to military personnel to expand the tools for VBD protection. With resolution of supportability and reliability challenges, these devices can provide protection to our military members, especially in stationary deployment situations.

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The Asian Tiger Mosquito, *Aedes Albopictus* (Skuse)